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A MARGINAL ANALYSIS STOCKPILE PLANNING PROGRAM

by

Ivan Taylor, JSORT

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by

Ivan Taylor, JSORT

Recommended by: K.R. Wheaton, JSORT

Approved by: G. Lafond, DOR(J&L)

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ABSTRACT

The NATO Defence Requirements Review (DRR) has developed 26 Planning Situations for Force Development and Stockpile Guidance. These Planning Situations range from potential Article 5 Operations, to Peace Support Operations and Other Security Interests. The Canadian Department of National Defence has been developing analytical methods for force planning using Scenarios. These methods have included balancing Cost and Risk using Marginal Analysis ("Best Bang for the Buck") algorithms. The salient feature of these models is that they result in an intuitive graphical presentation of Cost and Risk in which Risk is reduced as Cost increases. However, there is a state of diminishing returns in which inordinate Cost is incurred to remove the last percentages of Risk. The Canadian Marginal Analysis approach has been adapted, in the following paper, to the NATO Planning Situations to examine the Cost/Risk relationship in the Ammunition Stockpiles. Using this method, military decision-makers can develop an "optimal" Ammunition Stockpile that achieves "maximum" cost savings (i.e. the Peace Dividend) at "minimum" risk of running out of ammunition.

EXECUTIVE SUMMARY

1. The NATO Defence Requirements Review (DRR) has developed 26 Planning Situations which include potential Article 5 Operations, Peace Support Operations and Other Security Interests. The DRR states that NATO must be prepared to execute one Small Article 5 Operation and two other operations simultaneously on short notice and one Large Article 5 Operation and one other operation with significant warning time. Currently, NATO has two models for computing the ammunition stockpile requirements: ACROSS for Land, Air to Ground, and Air Defence; and the SACLANT Threat Model for Maritime stockpile planning. However, neither of these models can be adapted easily to handle the diversity of the Planning Situations described in the DRR. The Canadian Department of National Defence has been working with scenarios for the past year and has developed a number of analytical tools to balance Risk and Cost during Force Planning. One of these tools uses a heuristic called marginal analysis to get "the Best Bang for the Buck" while developing the Forces incrementally. This program has been adapted to the ammunition stockpile planning problem within the framework of the DRR Planning Situations.

2. In the Marginal Analysis Stockpile Planning Program (MASPP), the intelligence community will play an integral role in developing the data set. They will be called upon to establish realistic target lists, target values and target hardening factors for each Planning Situation. Also for the marginal analysis method to be employed, they would be required to estimate the likelihood of each Planning Situation combination occurring. It is recommended that a relative weighting scheme be employed to obtain an estimate of the probability of two or three Planning Situations occurring simultaneously.

3. Each Nation would need to identify the effectiveness multiplier for each ammunition type that would be assigned to each Planning Situation. This matrix could identify that certain types of munitions would not be considered in some Planning Situations because of the need to minimize collateral damage, or the desire to avoid escalation. This matrix would also be used to reduce the effectiveness of the munitions, from the ideal, in certain Planning Situations because of weather, terrain, etc.

4. Targeteers would be able to apply estimates of the effectiveness of each munition against each target type under ideal conditions in terms of the expected fraction of the target destroyed on average with each round of ammunition expended. Central to the

marginal analysis approach is the requirement that this relationship be one of diminishing returns. That is, the second round will destroy a smaller fraction of the Target than the first round on average and so on.

5. The marginal analysis technique attempts to maximize the Expected Target Value Destroyed for a given investment in ammunition. The objective function is an Expected Value because the Target Value that would be Destroyed in each Planning Situation combination is multiplied by the probability of each Planning Situation combination occurring and summed over all Planning Situation combinations.

6. The marginal analysis algorithm begins with a user-specified ammunition stockpile (e.g. the basic loads) then considers each type of ammunition, one at a time, to determine the Target Value Destroyed if it were optimally assigned to a Target in each Planning Situation combination. The Expected Target Value Destroyed for each type of ammunition, which is calculated using the probability of each combination of Planning Situations occurring, would be divided by the cost of the ammunition to determine the Bang for the Buck. The ammunition type with the Best Bang for the Buck would be recommended for purchase and the Target Value Remaining would be calculated for each Planning Situation combination. Then the algorithm would repeat the procedure to determine the next round of ammunition to recommend until the desired Fraction of the Total Expected Target Value has been destroyed or the Total Budget is expended.

7. The marginal analysis solution that is produced can be presented in a very intuitive graphical format. The Cost of the Ammunition Stockpile is on the X-axis and the Fraction of the Total Expected Target Value Destroyed is on the Y-axis. Each point on the curve is based on a vector of numbers of each type of ammunition recommended to be purchased. The points can be joined since each adjoining point represents another round of ammunition being recommended for purchase. The point of diminishing returns can be determined by NATO leadership which balances Cost and Effectiveness. As the Effectiveness increases, the Risk of running out of ammunition decreases. Therefore, it is easy to translate the Effectiveness value on the curve to a Risk value for decision-making.

8. A user-specified minimum stockpile is first allocated to the Small Article 5 and two other operations scenario. Then the On-Hand Stockpile is determined for the Small Article 5 scenarios. The algorithm restarts with this On-Hand Ammunition Stockpile and allocates it to the Large Article 5 scenarios to compute a new Expected Target Value

Destroyed. After that the algorithm works as before, adding ammunition one piece at a time, until the Expected Target Value Destroyed in the Large Article 5 scenarios reaches the desired level.

9. With this formulation, it can be seen that the Peace Dividend in the On-Hand Stockpile will have a cost and effectiveness curve for the Small Article 5 scenarios which is less demanding than the Readiness Requirements of the Large Article 5 scenarios. These on-hand stocks could be employed if necessary in the Large Article 5 scenarios but would not provide the same level of effectiveness. Additional investment would be required during the warning time to improve the effectiveness (and thereby reduce the risk of running out of ammunition). The marginal analysis program identifies the path of expenditure to ensure that the risk is reduced efficiently.

10. In summary, the DRR Planning Situations have been introduced to adapt the NATO Force Planning and Stockpile Guidance to the multiplicity of Post-Cold War Scenarios. However, the current models for Stockpile Planning (ACROSS and the SACLANT Threat Model) can not be adapted easily to handle these 26 Planning Situations and their combinations simultaneously. The Canadian approach of Marginal Analysis that was originally written for Force Development is adapted easily to Stockpile Planning under the Scenarios outlined by the DRR. Furthermore, the Canadian methodology allows NATO leadership to balance Cost and Risk by choosing an acceptable Fraction of Target Value Destroyed on which to base the Stockpile. The model displays an intuitive relationship between Cost and Risk that demonstrates a situation of diminishing returns as more resources are invested. By utilizing this information, NATO Stockpile Planners would be able to realize the expected Peace Dividend through the DRR Planning Situations. The Marginal Analysis approach is therefore recommended as a potential method for future NATO Stockpile Planning Models.

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A MARGINAL ANALYSIS STOCKPILE PLANNING PROGRAM

INTRODUCTION

1. The Marginal Analysis Stockpile Planning Program (MASPP) was developed for J4 Logistics Doctrine as an alternative to the ACROSS Model (Ref 1) developed by SHAPE and the Maritime Stockpile Planning Program developed by SACLANT (Ref 2) for ammunition Stockpile Planning . The problems inherent with the linear programming formulation in ACROSS were documented in Reference 3. The Maritime Stockpile Planning Program is a Monte Carlo Simulation and, like ACROSS, takes a worst-case approach based on the Cold War scenario. There is a moratorium on Stockpile Planning Guidance in NATO while the ADP Working Group addresses the problem of harmonization of the ACROSS Stockpile Planning Program and the Maritime Stockpile Planning Program with the NATO Defence Requirements Review (DRR) (Ref 4).

2. The DRR has identified 26 Planning Situations to respond to the multiplicity of the Post-Cold War threats. However, ACROSS and the Maritime Stockpile Planning Program are essentially single scenario models. The author previously developed a Marginal Analysis approach to Force Planning in the Canadian Forces based on the 11 Canadian Force Planning Scenarios (Ref 5). It was a relatively straightforward procedure to adapt the model described in Reference 5 to the Stockpile Planning problem of NATO. In the following paper, the resulting Marginal Analysis Stockpile Planning Program will be documented completely.

A NUMERICAL EXAMPLE OF MARGINAL ANALYSIS

3. Consider the situation of two small wars (PS1 and PS2) that could potentially erupt. NATO is committed to respond to one of them. PS1 has 60% probability of erupting and PS2 has 40% probability. Now consider three other potential operations (PS3, PS4 and PS5) that could be required at the same time as one of these small wars. NATO must be prepared to conduct any two of these three operations simultaneously

with one of the small wars. Table I shows example probabilities for each of these combinations occurring.

TABLE I
EXAMPLE PROBABILITIES FOR SIMULTANEOUS OPERATIONS

	PS3 AND PS4	PS3 AND PS5	PS4 AND PS5	TOTAL
PS1	0.200	0.100	0.300	0.600
PS2	0.200	0.133	0.067	0.400

4. We will consider three target types in each Planning Situation. The first target is worth 100K units of military value. The second target is worth 250K and the third target is worth 50K. Table II shows the number of targets in each Planning Situation along with the total target value.

TABLE II
EXAMPLE NUMBER OF TARGETS AND TOTAL TARGET VALUE

	PS1	PS2	PS3	PS4	PS5
Target 1	50	50	30	7	10
Target 2	50	10	25	5	4
Target 3	10	50	10	4	5
Total Value	18,000K	10,000K	9,750K	2,150K	2,250K

5. To obtain the starting value of the Total Expected Target Value, we must multiply the Total Target Value of Each Planning Situation combination by the probability of each Planning Situation combination occurring and then sum. The calculation of the Total Expected Target Value is shown in Table III. One can think of the Expected Value as a weighted average.

TABLE III
CALCULATION OF TOTAL EXPECTED TARGET VALUE

COMBINATION	TOTAL VALUE	PROBABILITY	EXPECTED VALUE
PS1,PS3,PS4	29,900K	0.200	5,980K
PS1,PS3,PS5	30,000K	0.100	3,000K
PS1,PS4,PS5	22,400K	0.300	6,720K
PS2,PS3,PS4	21,900K	0.200	4,380K
PS2,PS3,PS5	22,000K	0.133	2,933K
PS2,PS4,PS5	14,400K	0.067	960K
TOTAL		1.000	23,973K

6. For each munition type, we estimate an Ideal Single Shot Probability of Kill against each target. Table IV shows the example values for three types of munitions. Table V shows the target hardening factors for each Planning Situation and Table VI shows the degradation factors for each munition type in each Planning Situation. Notice that a munition degradation factor of 0.00 implies that that munition type would not be available for that Planning Situation.

TABLE IV
IDEAL SINGLE SHOT PROBABILITY OF KILL

	TARGET 1	TARGET 2	TARGET 3
MUNITION 1	0.10	0.20	0.30
MUNITION 2	0.20	0.10	0.10
MUNITION 3	0.30	0.30	0.20

TABLE V
TARGET HARDENING FACTORS

	PS1	PS2	PS3	PS4	PS5
TARGET 1	0.70	0.60	0.50	0.60	1.00
TARGET 2	0.80	0.70	0.60	0.50	0.90
TARGET 3	0.90	0.80	0.70	0.60	0.80

TABLE VI
MUNITION DEGRADATION FACTORS

	PS1	PS2	PS3	PS4	PS5
MUNITION 1	0.70	0.80	0.90	0.90	0.90
MUNITION 2	0.90	0.80	0.90	0.00	0.90
MUNITION 3	1.00	0.90	0.00	0.90	0.00

7. The Single Shot Probability of Kill of a Munition against a Target, as shown in Table IV, is modified for the Planning Situation by multiplying it by the Target Hardening Factor in Table V and the Munition Degradation Factor in Table VI. For example, the Modified Single Shot Probability of Kill for Munition 1 against Target 1 in Planning Situation 1 would be

$$(0.10)*(0.70)*(0.70) = 0.049.$$

8. The last piece of data required to employ the Marginal Analysis technique is the cost of each Munition Type. We have assumed that Munition 1 costs \$6K, Munition 2 costs \$12K and Munition 3 costs \$4K.

8. The Marginal Analysis algorithm goes through each Munition and each Planning Situation combination computing the optimal allocation of that Munition to a Target in the Planning Situation combination based on the Target Value Destroyed. Then it computes the Expected Target Value Destroyed for that Munition by multiplying the Target Value Destroyed in each Planning Situation combination times the probability of that Planning Situation combinations occurring. Table VII shows the example calculations for the first pass through the algorithm.

TABLE VII
EXAMPLE CALCULATIONS OF EXPECTED TARGET VALUE DESTROYED

COMBINATION	PROBABILITY	MUNITION 1	MUNITION 2	MUNITION 3
PS1,PS3,PS4	0.200	29.66K	18.67K	68.42K
PS1,PS3,PS5	0.100	43.22K	20.90K	68.42K
PS1,PS4,PS5	0.300	43.22K	20.90K	68.42K
PS2,PS3,PS4	0.200	29.52K	14.37K	51.83K
PS2,PS3,PS5	0.133	43.22K	20.90K	51.83K
PS2,PS4,PS5	0.067	43.22K	20.90K	51.83K
TOTAL	1.000	37.77K	19.14K	61.78K

9. Thus the Expected Target Value Destroyed by Munition 1 is 37.77K, by Munition 2 is 19.14K and by Munition 3 is 61.78K. Then the Bang for the Buck is calculated by dividing the Expected Target Value Destroyed by the cost of the Munition. Table VIII shows the results.

TABLE VIII
BANG FOR THE BUCK CALCULATIONS

	MUNITION 1	MUNITION 2	MUNITION 3
EXPECTED TARGET VALUE DESTROYED	37.77K	19.14K	61.78K
COST OF MUNITION	6K	12K	4K
BANG FOR THE BUCK	6.29	1.60	15.45

10. Since Munition 3 is Expected to Destroy 61.78K worth of Target Value and costs only 4K, its Bang for the Buck is 15.45 and would be selected for purchase after the first pass of the algorithm.

11. The values under Munition 3 in Table VII are subtracted from the Target Values in the Planning Situation combinations in Table III and then multiplied by the Probability of each Planning Situation combination occurring to get the new Target Value Remaining after the expenditure on Munition 3. Table IX shows the calculations.

TABLE IX
CALCULATION OF EXPECTED TARGET VALUE REMAINING

COMBINATION	TOTAL VALUE	PROBABILITY	EXPECTED VALUE
PS1,PS3,PS4	29,831K	0.200	5,966K
PS1,PS3,PS5	29,932K	0.100	2,993K
PS1,PS4,PS5	22,332K	0.300	6,700K
PS2,PS3,PS4	21,848K	0.200	4,370K
PS2,PS3,PS5	21,948K	0.133	2,926K
PS2,PS4,PS5	14,348K	0.067	956K
TOTAL		1.000	23,911K

12. As a check of our calculations, another way to calculate the Expected Target Value remaining would be to subtract the Expected Target Value Destroyed by Munition 3 from the Initial Total Target Value.

$$(23{,}973K) - (62K) = (23{,}911K).$$

The algorithm then repeats the process to determine the next Munition to purchase and stops when the Fraction of Expected Target Value Destroyed has reached the desired level.

PLANNING SITUATION LIKELIHOOD DATA

13. The data set for a larger example is shown in Annex B. With the Planning Situations, some are Large Article 5 Operations and some are Small Article 5 Operations. In Annex B, the first two scenarios are Large Article 5 and the next three are Small Article 5. The remaining six Operations are Peace Support Operations or Other Security Interests. We have employed weighting factors to estimate the relative probability of these Article 5 Operations occurring (see Tables X and XI).

TABLE X
PROBABILITY CALCULATION FOR LARGE ARTICLE 5 OPERATIONS

PLANNING SITUATION	WEIGHTING FACTOR	PROBABILITY
PS 1	5	0.625
PS 2	3	0.375

TABLE XI
PROBABILITY CALCULATIONS FOR SMALL ARTICLE 5 OPERATIONS

PLANNING SITUATION	WEIGHTING FACTOR	PROBABILITY
PS 3	3	0.500
PS 4	2	0.333
PS 5	1	0.167

14. The DRR states that NATO must be prepared to run one Small Article 5 Operation and two other Operations with on-hand stocks. With significant Warning (one to two years), it must be prepared to run one Large Article 5 Operation, and one Small Article 5 or one other type of Operation. Thus we must consider concurrent Operations in our model. Again, we can employ weighting factors to obtain the probabilities of these concurrent operations occurring as shown in Table XII for Large Article 5 Operations and Table XIII for Small Article 5 Operations.

TABLE XII
WEIGHTING FACTORS AND PROBABILITIES FOR LARGE ARTICLE 5 OPERATIONS

CONCURRENT OPERATION	PS 1 WEIGHT (PROB)	PS 2 WEIGHT (PROB)
PS 3	0 (0.000)	3 (0.049)
PS 4	4 (0.104)	4 (0.065)
PS 5	3 (0.078)	0 (0.000)
PS 6	2 (0.052)	1 (0.016)
PS 7	1 (0.026)	2 (0.033)
PS 8	5 (0.130)	3 (0.049)
PS 9	4 (0.104)	4 (0.065)
PS 10	3 (0.078)	5 (0.082)
PS 11	2 (0.052)	1 (0.016)
TOTAL PROB	(0.625)	(0.375)

15. The probability of Planning Situation 1 and Planning Situation 9 occurring simultaneously is 0.104 and this is four times as likely as Planning Situation 1 and Planning Situation 7 occurring together. The probability of Planning Situation 2 and Planning Situation 7 occurring at the same time is 0.033 and this is only half as likely as

Planning Situation 2 and Planning Situation 9 occurring together. The sum of all the probabilities in Table XII is 1.0.

16. For the Small Article 5 Operations in Table XIII, the probability of Planning Situation 3 occurring with Planning Situation 7 and Planning Situation 11 is 0.021. This is only half as likely as Planning Situation 3, Planning Situation 7 and Planning Situation 10 occurring together. All the possible combinations of one Small Article 5 Operation and two Other Operations are enumerated and the sum of all these probabilities is 1.0.

TABLE XIII
WEIGHTING FACTORS AND PROBABILITIES FOR SMALL ARTICLE 5 OPERATIONS

WITH PS 3 (TOTAL 0.50)	PS 7	PS 8	PS 9	PS 10	PS 11
PS 6	2 (0.042)	0 (0.000)	3 (0.063)	2 (0.042)	1 (0.021)
PS 7		3 (0.063)	1 (0.021)	2 (0.042)	1 (0.021)
PS 8			1 (0.021)	3 (0.063)	1 (0.021)
PS 9				2 (0.042)	1 (0.021)
PS 10					1 (0.021)

WITH PS 4 (TOTAL 0.33)	PS 7	PS 8	PS 9	PS 10	PS 11
PS 6	3 (0.036)	0 (0.000)	1 (0.012)	3 (0.036)	2 (0.024)
PS 7		1 (0.012)	3 (0.036)	1 (0.012)	2 (0.024)
PS 8			2 (0.024)	1 (0.012)	3 (0.036)
PS 9				1 (0.012)	2 (0.024)
PS 10					3 (0.036)

WITH PS 5 (TOTAL 0.17)	PS 7	PS 8	PS 9	PS 10	PS 11
PS 6	2 (0.011)	0 (0.000)	3 (0.017)	2 (0.011)	1 (0.006)
PS 7		3 (0.017)	1 (0.006)	2 (0.011)	3 (0.017)
PS 8			1 (0.006)	3 (0.017)	2 (0.011)
PS 9				2 (0.011)	3 (0.017)
PS 10					1 (0.006)

17. This level of detail is necessary because the Planning Situations may not be independent. For example, some Planning Situations may be mutually exclusive, like Planning Situation 6 and Planning Situation 8, while others might be more likely to occur together like Planning Situation 2 and Planning Situation 10.

TARGETS IN EACH PLANNING SITUATION

18. In MASPP, a Planning Situation is specified by its Targets. Each Target Type has a user-specified Value and each Planning Situation has a user-specified number of Targets of each Type. In the example data set, the Large Article 5 Operations have hundreds of targets of each type. The scale of the Small Article 5 Operations is an order of magnitude smaller and the Other Operations are a further order of magnitude smaller still (Annex B shows the Target Values and Number of Targets in each Planning Situation).

19. By multiplying the Target Values by the Number of Targets and summing in each Planning Situation, then multiplying this by the probabilities in the previous section, we can obtain the Expected Target Value in each set of Planning Situation combinations (see Table XIV). This is the starting point for the allocation process. The allocation of a chosen ammunition type in each Planning Situation combination will reduce the Target Value Remaining in that combination. When the Desired Fraction of Expected Target Value Destroyed is reached, the algorithm stops.

TABLE XIV
EXPECTED TARGET VALUES COMPUTED IN EXAMPLE DATA SET

PLANNING SITUATION COMBINATIONS	TOTAL EXPECTED TARGET VALUE
ONE LARGE ARTICLE 5 AND ONE OTHER	1,029,527
ONE SMALL ARTICLE 5 AND TWO OTHER	235,369

PLANNING SITUATION EFFECTIVENESS FACTORS

20. It may happen that a certain ammunition type may not be suitable in some Planning Situations because Commanders wish to limit collateral damage, escalation, etc. In Annex B, one can see a matrix which identifies the ammunition effectiveness factors in each Planning Situation. A '1.0' in the cell corresponding to the ammunition type and the Planning Situation is used to identify that that ammunition type is ideal for that Planning Situation. A '0.0' means it would not be available for that Planning Situation. A value between 0.0 and 1.0 means the performance of the ammunition is degraded from the ideal in that Planning Situation because of weather, terrain, etc.

21. Similarly, some targets may be harder to destroy in some Planning Situations than in others. A matrix in Annex B shows values between 0.0 and 1.0 which are used as multipliers to degrade the effectiveness of all ammunition types against this target in this Planning Situation. That is, if this value in the matrix was 0.5, all the ammunition effectiveness values against this target in this Planning Situation would be cut in half compared to the ideal values.

AMMUNITION COST, MINIMUM AND MAXIMUM HOLDINGS

22. In Annex B, the Cost of each Ammunition Type, the Minimum Holdings of each Ammunition Type (e.g. the Basic Load) and Maximum Holdings for the Small Article 5 scenarios and the Large Article 5 scenarios are shown in a Table. The Marginal Analysis algorithm is limited by the maximum values, so that once the maximum holding is reached no further purchase of that ammunition will be recommended. This allows a linkage between Stockpile Planning and Force Planning in that a Nation must have sufficient Weapon Systems to fire off the ammunition stockpile during the expected duration of the Planning Situation.

IDEAL AMMUNITION EFFECTIVENESS

23. The Ideal Ammunition Effectiveness is shown as a matrix in Annex B and can be thought of as the single shot probability of kill of one round of ammunition against one target under ideal conditions. This would be modified by the ammunition degradation factor and the target hardening factor in the particular Planning Situation. In the algorithm, we assume that there is a situation of diminishing returns. That is, if the first

shot has a modified single shot probability of kill of 0.5, then the first two shots have a probability of kill of (1.0-(1.0-0.5)^2) = 0.75 and the first three shots have a probability of kill of (1.0-(1.0-0.5)^3) = 0.875. Figure 1 shows the results graphically. We are never absolutely certain that we have killed the target but with more shots we have more confidence of kill.

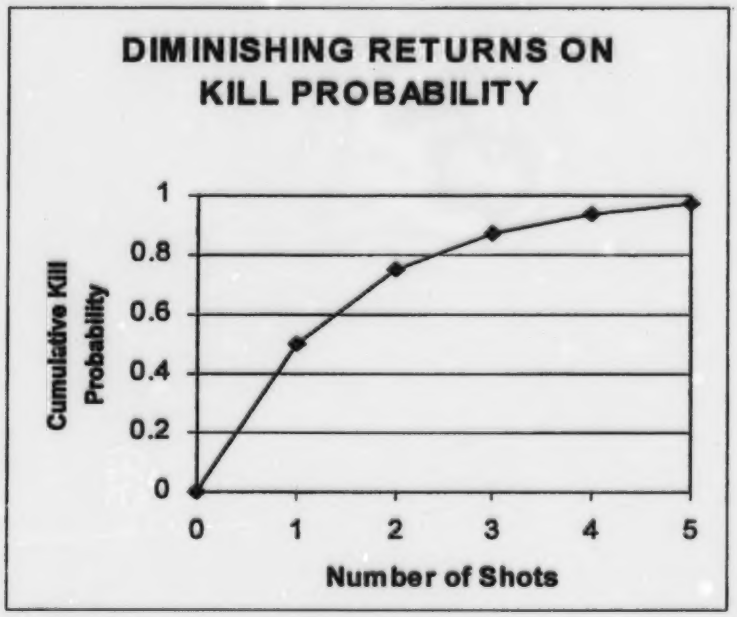

Figure 1: Diminishing Returns on Kill Probability

24. With more than one Target of the same type, we work with the Target Value. Thus, each shot would destroy an amount of the Target Value equal to

(Total Target Value Remaining)*
(1.0 – (1.0 – Modified Single Shot Kill Probability)^(1.0 / Number of Targets))

Thus, with the modified single shot kill probability of 0.5 and 3 Targets of value 1,000,000 units each, the first shot would destroy (3,000,000)*(1.0 - (1.0 - 0.5)^(1/3)) = 618,898 and the Target Value Remaining would be 3,000,000 – 618,898 = 2,381,102. The second shot would destroy (2,381,102)*(1.0 - (1.0 - 0.5)^(1/3)) = 491,220. The Target Value Remaining would be 2,381,102 – 491,220 = 1,889,882. The third shot would destroy (1,889,882)*(1.0 – (1.0 - 0.5)^(1/3)) = 389,882. The Total Target Value Destroyed would be 618,898 + 491,220 + 389,882 = 1,500,000 which equates to three shots at three targets with 0.5 modified single shot probability of kill. Similar to the

probability of kill, the Target Value Destroyed demonstrates a state of diminishing returns when there are multiple targets (see Figure 2).

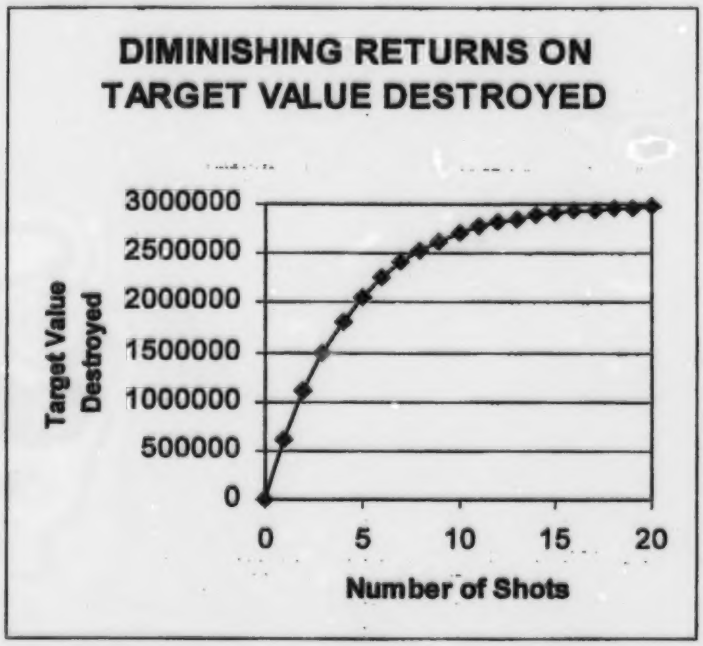

Figure 2: Diminishing Returns on Target Value Destroyed

THE MARGINAL ANALYSIS TECHNIQUE

25. The Marginal Analysis Technique is applied four times in the MASPP program (see Annex A). The first application assigns the minimum stock levels to the Small Article 5 scenarios. When all of the minimum stockpile is allocated, the program begins to purchase new ammunition using the Marginal Analysis Technique until the Desired Fraction of the Target Value is Destroyed for these Small Article 5 scenarios. The On-Hand Stockpile developed for the Small Article 5 scenarios is then allocated to the Large Article 5 scenarios in the third phase of the program. The Fraction of the Total Target Value Destroyed with this On-Hand Stockpile in the Large Article 5 scenarios is lower than the Fraction of the Total Target Value Destroyed in the Small Article 5 scenarios because the Large Article 5 scenarios have many more Targets to be Destroyed (see Figure 3). The final application of the Marginal Analysis Technique is applied to the Large Article 5 scenarios until the Desired Target Value Destroyed is reached for these scenarios.

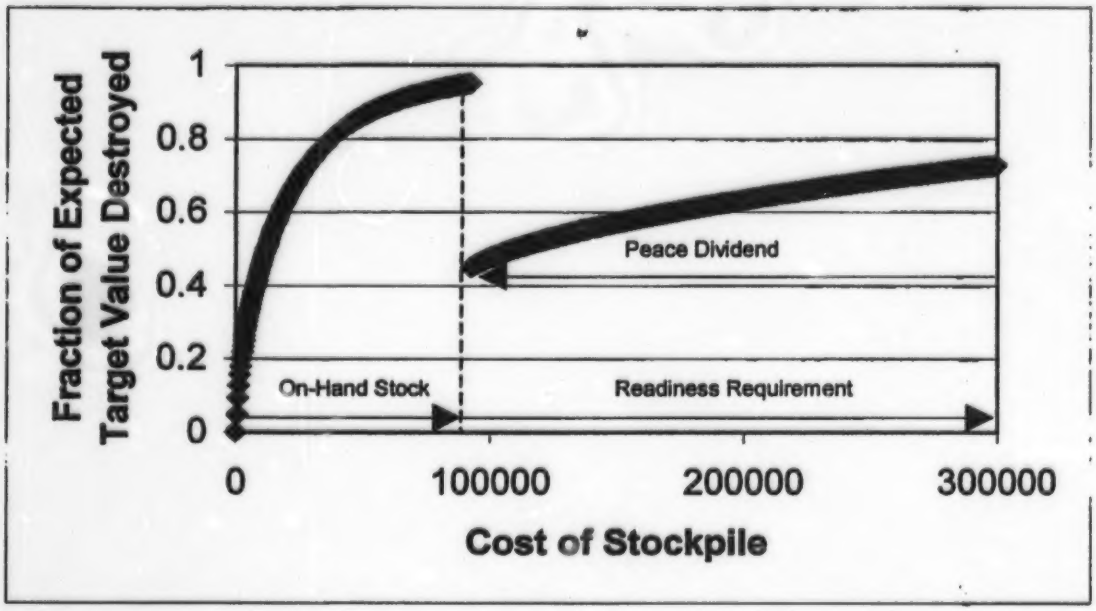

Figure 3: Example Results from the Marginal Analysis Technique

THE RESULTING PEACE DIVIDEND

26. Figure 3 shows the results of the Marginal Analysis Stockpile Planning Program for the example data set in Annex B. The detailed results to produce this graph are shown in Annex D. We can see that the first curve has the same basic shape as the previous diminishing returns curves. This curve shows the relationship between the Cost and Effectiveness of the Stockpile for the Small Article 5 Operation and two Other Operations (the On-Hand Stockpile). When the Desired Fraction of the Target Value is Destroyed (in this case, 0.95), the algorithm switches to the Large Article 5 Operation and one other operation. The more demanding requirements of these Operations causes the Fraction of the Total Target Value Destroyed, using the on-hand stocks, to drop significantly (to 0.45). Then the Marginal Analysis Technique begins working to increase the Fraction of the Total Target Value Destroyed to an acceptable level (i.e. 0.90) by purchasing additional ammunition (i.e. up to $677K) as part of the Readiness Requirement (Figure 3 has been arbitrarily cut off at $300K for display purposes). It should be noted that this significant expenditure to meet the Readiness Requirement could take one to two years. It is not necessary to have the Readiness Requirement on-hand. Therefore, the difference between the Total Cost of the Readiness Requirement

and the Total Cost of the On-Hand Stocks represents the savings associated with the Peace Dividend.

THE TIME ELEMENT

27. It should be noted that there is no explicit element of time in the Marginal Analysis algorithm. For example, the scenarios could be low intensity and last years or be high intensity and last days. The time factor is not considered explicitly. Only the target lists are considered in the Planning Situations and the Stockpile Planners will need enough ammunition to Destroy those Targets with a certain degree of confidence. Specifying realistic Maximum Ammunition Holdings is a way to link the Ammunition Stockpile to the Time Element and the Force Planning process.

LINKAGE TO FORCE PLANNING

28. In the Force Planning process, NATO planners would assign certain Forces to certain Planning Situations. These Forces would have a finite capability of firing ammunition at targets in the time available for the Planning Situation. By setting a Maximum on the Ammunition Holdings, the algorithm would limit the firing rate of the Force elements to realistic levels and reassign targets to other less utilized Force elements.

29. If one wishes to phase out a certain weapon system over a number of years and phase in another weapon system, one would only need to adjust the Maximum and Minimum Ammunition Holdings each year and MASPP would calculate the optimal stockpile to purchase during the transition. This would allow for very effective Force Planning by NATO Nations.

30. It may be desirable to run the model at least once with very large Maximum Holdings and very low Minimum Holdings to determine the most cost-effective Force Structure across the scenarios. That is, the resulting ammunition stockpile would suggest that some Force elements are more productive than others and that these Force elements should be acquired in larger numbers.

ATTRITION

31. The attrition of Force elements is not explicitly considered in MASPP because MASPP is not a combat simulation. It only allocates resources. However, attrition can be accounted for in the model through the input data; specifically through a combination of the Target Hardening Factors and the Maximum Ammunition Holdings. For example, Air Defence Units would protect certain Targets, thereby, making certain Ammunition Types less effective and by destroying attacking Force elements which would reduce the firing rate as reflected in the Maximum Holdings.

CONCLUSION

32. The Marginal Analysis Stockpile Planning Program (MASPP) was developed for NATO Stockpile Planning because of the increasing diveristy of missions of NATO in the future as described by the NATO Defence Requirements Review. The DRR is addressing the future needs of NATO by developing 26 Planning Situations that portray the diversity of threats in the Post-Cold War era. The DRR states that NATO must be ready to undertake three small operations simultaneously on short notice and be prepared to expand its capability over one or two years to undertake one large operation and one small operation simultaneously. The current NATO Stockpile Planning Models are single scenario worst-case approaches. It has been proposed by the model developers that hundreds of runs could be made using the existing models and the results compared to determine the "dominant" scenario. This would be the worst case scenario. Positioning one's self for any one particular case may not provide the flexibility for other likely contingencies.

33. Since MASPP is multi-scenario, all of the Planning Situations and their combinations are considered at the same time. The results are based on Expected Values and the calculation of Effectiveness (and Risk) is separated from the Scenarios so that these two aspects of the problem can be examined independently. All the Planning Situation combinations can be considered with MASPP, and not just one worst-case scenario that may not be applicable to other probable scenarios. That is, if MASPP develops a Stockpile in which 90% of the Expected Target Value will be Destroyed over all the Planning Situation combinations, then for any individual Planning Situation combination the Target Value Destroyed would be approximately 90% as well.

34. MASPP would be easier to maintain than the current NATO models. The program is so simple that the algorithm can be implemented in a few lines of computer code. The major activity in MASPP is handling the input and output routines.

35. This method produces graphical results are that are easy to interpret. Therefore, decision-makers should be able to make the necessary tradeoffs between Cost and Effectiveness (Risk) to ensure they are spending their budgets wisely. Furthermore, the Cost of increasing Effectiveness (reducing Risk) can be determined from the graph as well as the savings that can be obtained if increased Risk is accepted.

36. In summary, the DRR Planning Situations have been introduced to adapt the NATO Force Planning and Stockpile Guidance to the multiplicity of Post-Cold War Scenarios. However, the current models for Stockpile Planning (ACROSS and the SACLANT Threat Model) can not be adapted easily to handle these 26 Planning Situations and their combinations simultaneously. The Canadian approach of Marginal Analysis that was originally written for Force Development is adapted easily to Stockpile Planning under the Scenarios outlined by the DRR. Furthermore, the Canadian methodology allows NATO leadership to balance Cost and Risk by choosing an acceptable Fraction of Target Value Destroyed on which to base the Stockpile. The model displays an intuitive relationship between Cost and Risk that demonstrates a situation of diminishing returns as more resources are invested. By utilizing this information, NATO Stockpile Planners should be able to realize the expected Peace Dividend through the DRR Planning Situations. Therefore, it is recommended that the Marginal Analysis approach be considered for future NATO Stockpile Planning.

REFERENCES

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ANNEX A
DOR(J&L) RN 9901
APRIL 1999

THE MASPP FORTRAN CODE

Below is a listing of the FORTRAN 90 source code for the MASPP program.

```
c234567
c     This program uses marginal analysis to optimize the stockpile
c     of ammunition using NATO Planning Situations.
c
      common targval3(26,26,26,100,3),tottval(26,100),
     1       ammtarg(100,100),harden(26,100),degrade(26,100),
     2       itarval(100),numtars,numsit,numammo,ntarscn(26,100),
     3       prob1(26),prob2(26,26),prob3(26,26,26)
      real totprob(26)
      integer newammo(100),minammo(100),
     1        ncost(100),maxamm1(100),maxamm2(100)
      double precision b,best
      character*25 ammname(100),sitname(26),tarname(100),name,
     1                  infile,grfile,spfile
      print*,'The Stockpile Optimizer'
      print*,'Input File Name'
      read(*,*) infile
      print*,'Graphical Data Output File Name'
      read(*,*) grfile
      print*,'Stockpile Output File Name'
      read(*,*) spfile
      open(3,file=infile)
      open(4,file=grfile)
      open(5,file=spfile)
      read(3,*)
      read(3,*)
c      print*,'Number of Planning Situations'
      read(3,*)
      read(3,*) numsit
c      print*, numsit
      read(3,*)
      read(3,*)
      do 30 i=1,numsit
         prob1(i)=0.0
         do 20 j=1,numsit
            prob2(i,j)=0.0
            do 10 k=1,numsit
               prob3(i,j,k)=0.0
  10        continue
  20     continue
  30  continue
c      print*,'Large Article 5, Small Article 5'
      read(3,*) nlarge,nsmall
c     print*,nlarge,nsmall
      read(3,*)
      read(3,*)
      totprob1=0.0
```

```
      totprobs=0.0
      do 50 i=1,numsit
         read(3,*) sitname(i),prob1(i)
         if (i.le.nlarge) then
            totprob1=totprob1+prob1(i)
         elseif (i.le.nsmall) then
            totprobs=totprobs+prob1(i)
         endif
   50 continue
      do 51 i=1,nlarge
         prob1(i)=prob1(i)/totprob1
c         write(*,1050) prob1(i)
1050     format(' ',f10.2)
   51 continue
      do 52 i=nlarge+1,nsmall
         prob1(i)=prob1(i)/totprobs
c         write(*,1050) prob1(i)
   52 continue
      read(3,*)
      read(3,*)
      read(3,*)
      do 60 i=1,nlarge
         totprob(i)=0.0
         read(3,*) name,(prob2(i,j),j=nlarge+1,numsit)
         do 55 j=nlarge+1,numsit
            totprob(i)=totprob(i)+prob2(i,j)
   55    continue
   60 continue
      do 70 i=1,nlarge
         do 65 j=nlarge+1,numsit
            prob2(i,j)=(prob2(i,j)*prob1(i))/totprob(i)
   65    continue
c         write(*,1065) (prob2(i,j),j=nlarge+1,numsit)
1065     format (' ',11f7.2)
   70 continue
      read(3,*)
      read(3,*)
      do 80 i=nlarge+1,nsmall
         read(3,*) name
         read(3,*)
         totprob(i)=0.0
         do 75 j=nsmall+1,numsit-1
            read(3,*) name,(prob3(i,j,k),k=j+1,numsit)
            do 72 k=j+1,numsit
               totprob(i)=totprob(i)+prob3(i,j,k)
   72       continue
   75    continue
         read(3,*)
   80 continue
      do 90 i=nlarge+1,nsmall
         do 86 j=nsmall+1,numsit-1
            do 83 k=j+1,numsit
               prob3(i,j,k)=(prob3(i,j,k)*prob1(i))/totprob(i)
   83       continue
c            write(*,1065) (prob3(i,j,k),k=j+1,numsit)
   86    continue
   90 continue
c     print*,'Number of Target Types'
      read(3,*)
      read(3,*) numtars
c     print*,numtars
```

```
      read(3,*)
c      print*,'Target Values'
      read(3,*)
      do 100 m=1,numtars
         read(3,*) tarname(m),itarval(m)
c         write(*,900) tarname(m),itarval(m)
900      format(' ',a25,i10)
  100 continue
      read(3,*)
      exptarv=0.0
      read(3,*)
      read(3,*)
      do 102 m=1,numtars
         read(3,*) name,(ntarscn(i,m),i=1,numsit)
c         write(*,999) name,(ntarscn(i,m),i=1,numsit)
999      format(' ',a25,11i5)
         do 101 i=1,numsit
            tottval(i,m)=float(ntarscn(i,m))*float(itarval(m))
  101    continue
  102 continue
      read(3,*)
      read(3,*)
c      print*,'Target Hardening Factors'
      read(3,*)
      do 103 m=1,numtars
         read(3,*) name,(harden(i,m),i=1,numsit)
c         write (*,997) name,(harden(i,m),i=1,numsit)
997      format(' ',a25,11f5.2)
  103 continue
      read(3,*)
c      print*,'Number of Ammo Types'
      read(3,*)
      read(3,*) numammo
c      print*,numammo
      read(3,*)
      read(3,*)
      do 105 i=1,numsit
         read(3,*) name,(degrade(i,n),n=1,numammo)
c         write(*,998) name,(degrade(i,n),n=1,numammo)
998      format(' ',a25,60f5.2)
  105 continue
      read(3,*)
c      print*,'Ammo Effectiveness Matrix'
      read(3,*)
      read(3,*)
      nstart=0
      do 120 n=1,numammo
         read(3,*) ammname(n),ncost(n),minammo(n),maxamm1(n),
     1             maxamm2(n),(ammtarg(n,m),m=1,numtars)
c         write(*,910) ammname(n),ncost(n),minammo(n),maxamm1(n),
c     1                maxamm2(n),(ammtarg(n,m),m=1,numtars)
910      format(' ',a25,4i5,'  ',20f5.1)
  120 continue
      print*,'Desired Fraction of Expected Target Value Destroyed',
     1 ' (Small and Large)'
      read(*,*) fract1,fract2
920   format(2f10.4)
      print*,'Budget Limit'
      read(*,*) maxcost
c
c        marginal analysis technique for minimum stock levels
```

```
c        and peacetime operations
c
      print*,'Target Value Destroyed with Minimum Stockpile'
      ntotcos=0
      do 1310 i=nlarge+1,nsmall
         do 1309 j=nsmall+1,numsit-1
            do 1308 k=j+1,numsit
               do 1305 m=1,numtars
                  do 1304 l=1,3
                     if (l.eq.1) then
                        i1=i
                     elseif (l.eq.2) then
                        i1=j
                     else
                        i1=k
                     endif
                     targval3(i,j,k,m,l)=0.0
                     if (ntarscn(i1,m).gt.0) then
                        targval3(i,j,k,m,l)=float(ntarscn(i1,m))*
     1                       float(itarval(m))
                     endif
 1304             continue
 1305          continue
 1308       continue
 1309    continue
 1310 continue
      exptarv=0.0
      do 1321 m=1,numtars
         do 1320 i=nlarge+1,nsmall
            do 1315 j=nsmall+1,numsit-1
               do 1314 k=j+1,numsit
                  exptarv=exptarv+prob3(i,j,k)*
     1               (targval3(i,j,k,m,1)+targval3(i,j,k,m,2)+
     2               targval3(i,j,k,m,3))
 1314          continue
 1315       continue
 1320    continue
 1321 continue
      nstart=0
      nend1=0
      nend2=0
      do 1325 n=1,numammo
         nstart=nstart+minammo(n)
         nend1=nend1+maxamm1(n)
         nend2=nend2+maxamm2(n)
         newammo(n)=0
 1325 continue
      total=exptarv
      totfrac=0.0
      nbest=0
      xprint=0.01
      write(4,995)
995   format('   Expenditure So Far      Fraction of Expected'
     1 ' Target Value Destroyed')
      write(4,1000) ntotcos,totfrac
1000  format(' ',i10,30x,f10.7)
 1350 best=-1.0
      do 1400 n=1,numammo
         if (minammo(n).ne.0) then
            tval=0.0
            do 1360 i=nlarge+1,nsmall
```

```
                do 1352 j=nsmall+1,numsit-1
                   do 1354 k=j+1,numsit
                      call besttar3(i,j,k,n,m1,best1,11)
                      tval=tval+prob3(i,j,k)*best1
 1354                 continue
 1352              continue
 1360           continue
                b=tval/float(ncost(n))
c               print*,n,tval,ncost(n),b
                if (b.gt.best) then
                   best=b
                   bvalue=tval
                   nbest=n
                endif
             endif
 1400 continue
c
c     compute new target value remaining
c
      minammo(nbest)=minammo(nbest)-1
      newammo(nbest)=newammo(nbest)+1
      call newval3(nbest,nlarge,nsmall)
      total=total-bvalue
      ntotal=ntotal+1
      nstart=nstart-1
      totfrac=1.0-total/exptarv
      ntotcos=ntotcos+ncost(nbest)
      if (totfrac.gt.xprint) then
         write(4,1000) ntotcos,totfrac
         xprint=xprint+0.01
      endif
      if (nstart.gt.0) then
         goto 1350
      endif
      nbest=0
      write(4,1000) ntotcos,totfrac
      write(*,1000) ntotcos,totfrac
c
c        marginal analysis for peacetime stock levels
c
      print*,'Cost of On-Hand Stockpile'
 2350 best=-1.0
      do 2400 n=1,numammo
         if (newammo(n).lt.maxamm1(n)) then
            tval=0.0
            do 2360 i=nlarge+1,nsmall
               do 2358 j=nsmall+1,numsit-1
                  do 2356 k=j+1,numsit
                     call besttar3(i,j,k,n,m1,best1,11)
                     tval=tval+prob3(i,j,k)*best1
 2356                continue
 2358             continue
 2360          continue
c              print*,n,tval
               b=tval/float(ncost(n))
               if (b.gt.best) then
                  best=b
                  bvalue=tval
                  nbest=n
               endif
            endif
```

```
 2400 continue
c
c     compute new target value remaining
c
      newammo(nbest)=newammo(nbest)+1
      call newval3(nbest,nlarge,nsmall)
      total=total-bvalue
      ntotal=ntotal+1
      totfrac=1.0-total/exptarv
      ntotcos=ntotcos+ncost(nbest)
      if (totfrac.gt.xprint) then
         write(4,1000) ntotcos,totfrac
         xprint=xprint+0.01
      endif
      if (ntotcos.gt.maxcost.or.ntotal.ge.nend1) then
         goto 2500
      endif
      if (totfrac.lt.fract1) then
         goto 2350
      endif
 2500 write(4,1000) ntotcos,totfrac
      write(*,1000) ntotcos,totfrac
      write(5,2502)
2502  format(' On-Hand Stockpile')
      call prinres(numammo,ammname,newammo,ntotcos,totfrac)
      do 2501 n=1,numammo
         minammo(n)=newammo(n)
 2501 continue
c
c         marginal analysis for on-hand stocks in wartime scenarios
c
      print*,'Fraction of Target Value Destroyed with On-Hand Stockpile'
      exptarv=0.0
      do 3313 i=1,nlarge
         do 3312 j=nlarge+1,numsit
            do 3311 m=1,numtars
               do 3310 l=1,2
                  if (l.eq.1) then
                     il=i
                  else
                     il=j
                  endif
                  targval3(i,j,1,m,l)=0.0
                  if (ntarscn(il,m).ne.0) then
                     targval3(i,j,1,m,l)=float(ntarscn(il,m))*
     1                    float(itarval(m))
                  endif
 3310          continue
 3311       continue
 3312    continue
 3313 continue
       do 3321 m=1,numtars
          do 3320 i=1,nlarge
             do 3316 j=nlarge+1,numsit
                exptarv=exptarv+prob2(i,j)*
     1               (targval3(i,j,1,m,1)+targval3(i,j,1,m,2))
 3316        continue
 3320    continue
 3321 continue
      nstart=0
      do 3325 n=1,numammo
```

```
         nstart=nstart+minammo(n)
         newammo(n)=0
 3325 continue
      ntotal=0
      ntotcos=0
      total=exptarv
      totfrac=0.0
      xprint=0.01
      nbest=0
      bvalue=0.0
      write(4,*)
c      write(4,1000) ntotcos,totfrac
 3350 best=-1.0
      do 3400 n=1,numammo
         if (minammo(n).ne.0) then
            tval=0.0
            do 3360 i=1,nlarge
               do 3355 j=nlarge+1,numsit
                  call besttar2(i,j,n,m1,best1,11)
                  tval=tval+prob2(i,j)*best1
 3355          continue
 3360       continue
c           print*,n,tval
            b=tval/float(ncost(n))
            if (b.gt.best) then
               best=b
               bvalue=tval
               nbest=n
            endif
         endif
 3400 continue
c
c     compute new target value remaining
c
      minammo(nbest)=minammo(nbest)-1
      newammo(nbest)=newammo(nbest)+1
      call newval2(nbest,nlarge)
      total=total-bvalue
      ntotal=ntotal+1
      nstart=nstart-1
      totfrac=1.0-total/exptarv
      ntotcos=ntotcos+ncost(nbest)
      if (totfrac.gt.xprint) then
c         write(*,1000) ntotcos,totfrac
         xprint=xprint+0.01
      endif
c      if (ntotal.eq.1) stop
      if (nstart.gt.0) then
         goto 3350
      endif
      nbest=0
      write(4,1000) ntotcos,totfrac
      write(*,1000) ntotcos,totfrac
c
c        marginal analysis for readiness requirements in
c        wartime scenarios
c
      print*,'Cost of Readiness Requirement'
 4350 best=-1.0
      do 4400 n=1,numammo
         if (newammo(n).lt.maxamm2(n)) then
```

```
            tval=0.0
            do 4360 i=1,nlarge
               do 4355 j=nlarge+1,numsit
                  call besttar2(i,j,n,m1,best1,l1)
                  tval=tval+prob2(i,j)*best1
 4355          continue
 4360       continue
c           print*,n,tval
            b=tval/float(ncost(n))
            if (b.gt.best) then
               best=b
               bvalue=tval
               nbest=n
            endif
         endif
 4400 continue
c
c     compute new target value remaining
c
      newammo(nbest)=newammo(nbest)+1
      call newval2(nbest,nlarge)
      total=total-bvalue
      ntotal=ntotal+1
      totfrac=1.0-total/exptarv
      ntotcos=ntotcos+ncost(nbest)
      if (totfrac.gt.xprint) then
         write(4,1000) ntotcos,totfrac
         xprint=xprint+0.01
      endif
      if (ntotcos.gt.maxcost.or.ntotal.ge.nend2) then
         goto 4500
      endif
      if (totfrac.lt.fract2) then
         goto 4350
      endif
 4500 write(4,1000) ntotcos,totfrac
      write(*,1000) ntotcos,totfrac
      write(5,4501)
4501  format(' Readiness Requirements')
      call prinres(numammo,ammname,newammo,ntotcos,totfrac)
      stop
      end
c
      subroutine besttar2(i,j,n,m,best,l)
      common targval3(26,26,26,100,3),tottval(26,100),
     1       ammtarg(100,100),harden(26,100),degrade(26,100),
     2       itarval(100),numtars,numsit,numammo,ntarscn(26,100),
     3       prob1(26),prob2(26,26),prob3(26,26,26)
      best=0.0
      m=0
      l=0
c      if (degrade(i,n).le.0.0.and.degrade(j,n).le.0.0) then
c         return
c      endif
      do 6010 m1=1,numtars
         if (tottval(i,m1).gt.0.0) then
            good=targval3(i,j,1,m1,1)*(1.0-(1.0-
     1           ammtarg(n,m1)*degrade(i,n)*harden(i,m1))**
     2           (1.0/float(ntarscn(i,m1))))
            if (good.gt.best) then
               best=good
```

```
                m=m1
                l=1
             endif
          endif
          if (tottval(j,m1).gt.0.0) then
             good=targval3(i,j,1,m1,2)*(1.0-(1.0-
     1            ammtarg(n,m1)*degrade(j,n)*harden(j,m1))**
     2            (1.0/float(ntarscn(j,m1))))
             if (good.gt.best) then
                best=good
                m=m1
                l=2
             endif
          endif
 6010 continue
c      write(*,7000) i,j,n,m,l,best
7000  format(' ',5i10,f15.2)
      return
      end
c
      subroutine besttar3(i,j,k,n,m,best,l)
      common targval3(26,26,26,100,3),tottval(26,100),
     1       ammtarg(100,100),harden(26,100),degrade(26,100),
     2       itarval(100),numtars,numsit,numammo,ntarscn(26,100),
     3       prob1(26),prob2(26,26),prob3(26,26,26)

      best=0.0
      m=0
      l=0
c      if (degrade(i,n).le.0.0.and.degrade(j,n).le.0.0.and.
c     1    degrade(k,n).le.0.0) then
c         return
c      endif
      do 9010 m1=1,numtars
         if (tottval(i,m1).gt.0.0) then
            good=targval3(i,j,k,m1,1)*(1.0-(1.0-
     1            ammtarg(n,m1)*degrade(i,n)*harden(i,m1))**
     2            (1.0/float(ntarscn(i,m1))))
            if (good.gt.best) then
               best=good
               m=m1
               l=1
            endif
         endif
         if (tottval(j,m1).gt.0.0) then
            good=targval3(i,j,k,m1,2)*(1.0-(1.0-
     1            ammtarg(n,m1)*degrade(j,n)*harden(j,m1))**
     2            (1.0/float(ntarscn(j,m1))))
            if (good.gt.best) then
               best=good
               m=m1
               l=2
            endif
         endif
         if (tottval(k,m1).gt.0.0) then
            good=targval3(i,j,k,m1,3)*(1.0-(1.0-
     1            ammtarg(n,m1)*degrade(k,n)*harden(k,m1))**
     2            (1.0/float(ntarscn(k,m1))))
            if (good.gt.best) then
               best=good
               m=m1
```

```
                l=3
              endif
            endif
 9010   continue
c         write(*,9000) i,j,k,n,m,l,best
9000    format(' ',6i10,f15.2)
        return
        end
c
        subroutine newval2(iammo,nlarge)
        common targval3(26,26,26,100,3),tottval(26,100),
     1         ammtarg(100,100),harden(26,100),degrade(26,100),
     2         itarval(100),numtars,numsit,numammo,ntarscn(26,100),
     3         prob1(26),prob2(26,26),prob3(26,26,26)

        real xbest(26,26)
        integer itarg(26,26),l(26,26)
        do 6050 i=1,nlarge
           do 6040 j=nlarge+1,numsit
              xbest(i,j)=0.0
              itarg(i,j)=0
              l(i,j)=0
              if (prob2(i,j).ne.0.0) then
                 call besttar2(i,j,iammo,ntarg1,best1,l1)
                 xbest(i,j)=best1
                 l(i,j)=l1
                 itarg(i,j)=ntarg1
              endif
 6040      continue
 6050   continue
        do 6070 i=1,nlarge
           do 6060 j=nlarge+1,numsit
              if (l(i,j).gt.0.and.itarg(i,j).gt.0) then
                 targval3(i,j,1,itarg(i,j),l(i,j))=
     1              targval3(i,j,1,itarg(i,j),l(i,j))-
     2              xbest(i,j)
              endif
 6060      continue
 6070   continue
        return
        end
c
        subroutine newval3(iammo,nlarge,nsmall)
        common targval3(26,26,26,100,3),tottval(26,100),
     1         ammtarg(100,100),harden(26,100),degrade(26,100),
     2         itarval(100),numtars,numsit,numammo,ntarscn(26,100),
     3         prob1(26),prob2(26,26),prob3(26,26,26)
        real xbest(26,26,26)
        integer itarg(26,26,26),l(26,26,26)
        tval=0.0
        do 7050 i=nlarge+1,nsmall
           do 7040 j=nsmall+1,numsit-1
              do 7030 k=j+1,numsit
                 xbest(i,j,k)=0.0
                 itarg(i,j,k)=0
                 l(i,j,k)=0
                 if (prob3(i,j,k).ne.0.0) then
                    call besttar3(i,j,k,iammo,ntarg1,best1,l1)
                    xbest(i,j,k)=best1
                    l(i,j,k)=l1
                    itarg(i,j,k)=ntarg1
```

```
               endif
               tval=tval+xbest(i,j,k)*prob3(i,j,k)
 7030        continue
 7040     continue
 7050  continue
c       print*,'best',iammo,tval
       do 7080 i=nlarge+1,nsmall
          do 7070 j=nsmall+1,numsit-1
             do 7060 k=j+1,numsit
c               write(4,7051) i,j,k,itarg(i,j,k),l(i,j,k)
c7051           format(5i10)
                if (l(i,j,k).gt.0.and.itarg(i,j,k).gt.0) then
                   targval3(i,j,k,itarg(i,j,k),l(i,j,k))=
     1                targval3(i,j,k,itarg(i,j,k),l(i,j,k))-
     2                xbest(i,j,k)
                endif
c               write(*,7500) i,j,k,itarg(i,j,k),l(i,j,k),
c     1              targval3(i,j,k,itarg(i,j,k),l(i,j,k)),
c     2              xbest(i,j,k)
7500            format(' ',5i7,2f10.2)
 7060        continue
 7070     continue
 7080  continue
       return
       end
c
       subroutine prinres(numammo,ammname,newammo,ntotcos,totfrac)
       integer newammo(100)
       character*25 ammname(100)
c       write(5,8500)
8500   format(' Final Results')
       do 8599 n=1,numammo
          write(5,8010) ammname(n),newammo(n)
8010      format(' ',a25,i10)
 8599  continue
       write(5,8000) totfrac
8000   format(' Fraction of Expected Target Value Destroyed ',f10.7)
       write(5,8100) ntotcos
8100   format(' Total Cost  ',i15)
       return
       end
```

ANNEX B
DOR(J&L) RN 9901
APRIL 1999

EXAMPLE INPUT FILE FOR MASPP

Below is an example input file for MASPP with 11 Planning Situations, 20 Target Types, and 60 Ammunition Types. This was considered a reasonable example to prove the concept that MASPP could be used for complex scenarios.

```
STOCKPILE OPTIMIZER

Number of Planning Situations
11

Large and Small Art 5 Scenarios
2,5

Situation Name     Weight
'Situation 1'        5
'Situation 2'        3
'Situation 3'        3
'Situation 4'        2
'Situation 5'        1
'Situation 6'        0
'Situation 7'        0
'Situation 8'        0
'Situation 9'        0
'Situation 10'       0
'Situation 11'       0

Large Article 5 Operation and One Other
                3  4  5  6  7  8  9 10 11
'Situation 1'   0  4  3  2  1  5  4  3  2
'Situation 2'   3  4  0  1  2  3  4  5  1

Small Article 5 Operation and Two Other
'Situation 3'
                7  8  9 10 11
'Situation 6'   2  0  3  2  1
'Situation 7'      3  1  2  1
'Situation 8'         1  3  1
'Situation 9'            2  1
'Situation 10'              1

'Situation 4'
                7  8  9 10 11
'Situation 6'   3  0  1  3  2
'Situation 7'      1  3  1  2
'Situation 8'         2  1  3
'Situation 9'            1  2
'Situation 10'              3

'Situation 5'
                7  8  9 10 11
```

'Situation 6'	2	0	3	2	1
'Situation 7'		3	1	2	3
'Situation 8'			1	3	2
'Situation 9'				2	3
'Situation 10'					1

Number of Target Types
20

Target Type	Target Value
'Targ1'	100
'Targ2'	250
'Targ3'	50
'Targ4'	300
'Targ5'	100
'Targ6'	150
'Targ7'	110
'Targ8'	10
'Targ9'	175
'Targ10'	500
'Targ11'	900
'Targ12'	750
'Targ13'	100
'Targ14'	120
'Targ15'	125
'Targ16'	500
'Targ17'	250
'Targ18'	130
'Targ19'	150
'Targ20'	450

Target Types for Scenario Matrix

Target Type	1	2	3	4	5	6	7	8	9	10	11
'Targ 1'	300	100	50	50	30	7	10	5	6	12	1
'Targ 2'	200	100	50	10	25	0	4	0	4	0	3
'Targ 3'	100	300	10	50	10	4	0	4	0	5	0
'Targ 4'	700	100	10	10	10	0	15	0	0	10	0
'Targ 5'	100	500	10	10	50	0	20	0	0	40	10
'Targ 6'	100	100	10	15	20	5	6	7	80	0	0
'Targ 7'	100	100	10	10	50	10	20	30	40	50	60
'Targ 8'	100	100	10	10	10	0	0	0	0	5	5
'Targ 9'	100	100	10	10	10	0	30	0	20	0	10
'Targ 10'	100	500	60	25	10	0	0	5	5	5	5
'Targ 11'	100	100	50	50	50	1	1	1	1	1	1
'Targ 12'	300	100	15	10	25	0	5	0	5	0	7
'Targ 13'	100	200	10	10	10	2	0	2	0	2	0
'Targ 14'	500	100	10	25	10	0	5	0	0	5	0
'Targ 15'	100	200	10	10	50	0	20	0	0	30	10
'Targ 16'	100	100	50	25	50	1	5	10	1	0	0
'Targ 17'	100	100	10	10	25	5	5	10	10	10	10
'Targ 18'	100	100	10	10	10	0	0	0	0	50	50
'Targ 19'	100	100	10	10	10	0	40	0	40	0	40
'Targ 20'	100	500	50	50	10	0	0	50	50	50	50

Target Hardening Factors

	1	2	3	4	5	6	7	8	9	10	11
'Targ 1'	0.9	0.8	0.7	0.6	0.5	0.6	0.7	0.8	0.9	1.0	1.0
'Targ 2'	0.1	0.9	0.8	0.7	0.6	0.5	0.6	0.7	0.8	0.9	1.0
'Targ 3'	0.2	0.1	0.9	0.8	0.7	0.6	0.5	0.6	0.7	0.8	0.9
'Targ 4'	0.3	0.2	0.1	0.9	0.8	0.7	0.6	0.5	0.6	0.7	0.8
'Targ 5'	0.4	0.3	0.2	0.1	0.9	0.8	0.7	0.6	0.5	0.6	0.7

```
'Targ 6'    0.5  0.4  0.3  0.2  0.1  0.9  0.8  0.7  0.6  0.5  0.6
'Targ 7'    0.6  0.5  0.4  0.3  0.2  0.1  0.9  0.8  0.7  0.6  0.5
'Targ 8'    0.7  0.6  0.5  0.4  0.3  0.2  0.1  0.9  0.8  0.7  0.6
'Targ 9'    0.8  0.7  0.6  0.5  0.4  0.3  0.2  0.1  0.9  0.8  0.7
'Targ 10'   0.9  0.8  0.7  0.6  0.5  0.6  0.7  0.8  0.9  1.0  1.0
'Targ 11'   0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  0.8  0.7
'Targ 12'   0.1  0.9  0.8  0.7  0.6  0.5  0.6  0.7  0.8  0.9  1.0
'Targ 13'   0.2  0.1  0.9  0.8  0.7  0.6  0.5  0.6  0.7  0.8  0.9
'Targ 14'   0.3  0.2  0.1  0.9  0.8  0.7  0.6  0.5  0.6  0.7  0.8
'Targ 15'   0.4  0.3  0.2  0.1  0.9  0.8  0.7  0.6  0.5  0.6  0.7
'Targ 16'   0.5  0.4  0.3  0.2  0.1  0.9  0.8  0.7  0.6  0.5  0.6
'Targ 17'   0.6  0.5  0.4  0.3  0.2  0.1  0.9  0.8  0.7  0.6  0.5
'Targ 18'   0.7  0.6  0.5  0.4  0.3  0.2  0.1  0.9  0.8  0.7  0.6
'Targ 19'   0.8  0.7  0.6  0.5  0.4  0.3  0.2  0.1  0.9  0.8  0.7
'Targ 20'   0.9  0.8  0.7  0.6  0.5  0.4  0.3  0.2  0.1  0.9  0.8

Number of Ammo Types
60

                                  Ammunition Type Applied to Situations
                1    2    3    4    5    6    7    8    9   10   11   12   13   14
15  16  17  18  19   20   21   22   23   24   25   26   27   28   29   30   31   32
33  34  35  36  37   38   39   40   41   42   43   44   45   46   47   48   49   50
51  52  53  54  55   56   57   58   59   60
'Situation 1'   1    0  0.5  0  0.7  0    1    0  0.8  0    1    0    1    0
0.9  0   1   0   1    0  0.9  0    1    0    1    0    1    0    1    0  0.7  0
1    0 0.8  0   1    0    1    0  0.9  0    1    0    1    0    1    0    1    0
0.9  0   1   0 0.9  0    1    0  0.2  0
'Situation 2'   0    1    0  0.5  0  0.7  0    1    0  0.8  0    1    0    1
0  0.9  0   1   0    1    0  0.9  0    1    0    1    0    1    0    1    0  0.7
0    1   0 0.8  0    1    0    1    0  0.9  0    1    0    1    0    1    0    1
0  0.9  0   1   0  0.9  0    1    0  0.2
'Situation 3'  0.3  0.1  1    0  0.5  0  0.7  0    1    0  0.8  0    1    0
1    0 0.9  0   1    0    1    0  0.9  0    1    0    1    0    1    0    1    0
0.7  0   1   0 0.8  0    1    0    1    0  0.9  0    1    0    1    0    1    0
1    0 0.9  0   1    0  0.9  0    1    0
'Situation 4'   0  0.5  0.7  1    0  0.5  0  0.7  0    1    0  0.8  0    1
0    1   0 0.9  0    1    0    1    0  0.9  0    1    0    1    0    1    0    1
0  0.7  0   1   0  0.8  0    1    0    1    0  0.9  0    1    0    1    0    1
0    1   0 0.9  0    1    0  0.9  0    1
'Situation 5'  0.2  0.1  0.3  0.4  1    0  0.5  0  0.7  0    1    0  0.8  0
1    0   1   0 0.9  0    1    0    1    0  0.9  0    1    0    1    0    1    0
1    0 0.7  0   1    0  0.8  0    1    0    1    0  0.9  0    1    0    1    0
1    0   1   0 0.9  0    1    0  0.9  0
'Situation 6'  0.4  0.5  0.1  0.9  0.5  1    0  0.5  0  0.7  0    1    0  0.8
0    1   0   1   0  0.9  0    1    0    1    0  0.9  0    1    0    1    0    1
0    1   0 0.7  0    1    0  0.8  0    1    0    1    0  0.9  0    1    0    1
0    1   0   1   0  0.9  0    1    0  0.9
'Situation 7'    0    0  0.5  0.7  0.5  0.6  1    0  0.5  0  0.7  0    1    0
0.8  0   1   0   1    0  0.9  0    1    0    1    0  0.9  0    1    0    1    0
1    0   1   0 0.7  0    1    0  0.8  0    1    0    1    0  0.9  0    1    0
1    0   1   0   1    0  0.9  0    1    0
'Situation 8'  0.6  0.7  0.8  0    1    0  0.1  1    0  0.5  0  0.7  0    1
0  0.8  0   1   0    1    0  0.9  0    1    0    1    0  0.9  0    1    0    1
0    1   0   1   0  0.7  0    1    0  0.8  0    1    0    1    0  0.9  0    1
0    1   0   1   0    1    0  0.9  0    1
'Situation 9'  0.5  0.4  0.3  0.7  0.8  0.9  0.1  0.9  1    0  0.5  0  0.7  0
1    0 0.8  0   1    0    1    0  0.9  0    1    0    1    0  0.9  0    1    0
1    0   1   0   1    0  0.7  0    1    0  0.8  0    1    0    1    0  0.9  0
1    0   1   0   1    0    1    0  0.9  0
'Situation 10' 0.3  0.4  0.5  0.6  0.7  0.8  0.9  1    0  1    0  0.5  0  0.7
0    1   0 0.8  0    1    0    1    0  0.9  0    1    0    1    0  0.9  0    1
```

```
0   1   0   1   0   1   0  0.7  0   1   0  0.8  0   1   0   1   0  0.9
0   1   0   1   0   1   0   1   0  0.9
'Situation 11' 0.4 0.5 0.6 0.7 0.8 0.9  1   0   0   0   1   0  0.5  0
0.7  0   1   0  0.8  0   1   0   1   0  0.9  0   1   0   1   0  0.9  0
1   0   1   0   1   0   1   0  0.7  0   1   0  0.8  0   1   0   1   0
0.9  0   1   0   1   0   1   0   1   0
```

Ammo versus Target Effectiveness

```
          Cost Min  Max1  Max2   1   2   3   4   5   6   7   8   9  10
11  12  13  14  15  16  17  18  19  20
'Mun 1'     6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 2'    12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 3'     4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 4'    12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 5'    24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 6'     6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 7'    12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 8'     4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 9'    12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 10'   24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 11'    6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 12'   12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 13'    4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 14'   12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 15'   24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 16'    6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 17'   12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 18'    4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 19'   12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 20'   24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 21'    6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 22'   12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 23'    4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 24'   12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 25'   24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
```

```
'Mun 26'   6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 27'  12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 28'   4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 29'  12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 30'  24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 31'   6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 32'  12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 33'   4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 34'  12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 35'  24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 36'   6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 37'  12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 38'   4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 39'  12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 40'  24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 41'   6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 42'  12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 43'   4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 44'  12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 45'  24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 46'   6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 47'  12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 48'   4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 49'  12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 50'  24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
'Mun 51'   6   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 52'  12   1   1000 10000  0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 53'   4   1   1000 10000   0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 54'  12   1   1000 10000  0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 55'  24   1   1000 10000  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
```

```
'Mun 56'    6    1    1000 10000   0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.1
0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
'Mun 57'   12    1    1000 10000   0.2 0.1  0   0  0.1  0  0.2  0  0.1  0
0.1  0  0.2  0  0.1 0.1 0.1  0  0.1 0.2
'Mun 58'    4    1    1000 10000    0  0.3  0  0.4  0  0.2  0  0.2  0  0.2
0  0.1  0  0.3  0  0.1  0  0.2  0  0.4
'Mun 59'   12    1    1000 10000   0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
'Mun 60'   24    1    1000 10000   0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.9
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.1 0.2
```

ANNEX C
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THE MASPP RUN-TIME INSTRUCTIONS

To run MASPP.EXE in MS-DOS, type A:\MASPP and then answer the questions asked. You need a properly formated input file. You will specify two output files: one for the graphical data and one for the stockpile results. You will also be asked to provide the Desired Expected Target Value Destroyed for the Small Article 5 and Large Article 5 Operations and the overall Budget Limit. An example is provided below with the user input in bold. The example was run overnight on a Pentium II computer.

```
The Stockpile Optimizer
Input File Name
a:maspp.dat
Graph Output File Name
a:masgr.out
Stockpile Output File Name
a:massp.out
Desired Fraction of Expected Target Value Destroyed (Small and Large)
0.95,0.90
Budget Limit
1000000
Target Value Destroyed with Minimum Stockpile
      696                                .0490409
Cost of On-Hand Stockpile
    92474                                .9500031
Fraction of Target Value Destroyed with On-Hand Stockpile
    92474                                .4505509
Cost of Readiness Requirement
   677442                                .9000002
Stop - Program terminated.
```

ANNEX D
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EXAMPLE OF MASPP GRAPHICAL DATA OUTPUT

The file shown below can be opened in Microsoft Excel and a graph produced similar to the one shown in the text of this report. Notice there is a break line at Expenditure 92474 when the algorithm switches from the Small Article 5 to the Large Article 5 Operations.

Expenditure So Far	Fraction of Expected Target Value Destroyed
0	.0000000
42	.0114048
102	.0213040
206	.0321202
312	.0402899
696	.0490409
702	.0504989
750	.0611306
798	.0706846
852	.0803987
912	.0900579
984	.1003543
1062	.1102364
1152	.1202901
1254	.1303127
1380	.1411633
1498	.1503946
1634	.1602096
1784	.1703466
1940	.1802694
2104	.1901229
2278	.2000227
2466	.2102065
2656	.2200425
2858	.2300693
3072	.2402684
3298	.2506116
3534	.2610077
3746	.2700076
3992	.2800735
4246	.2900775
4508	.3000552
4780	.3100503
5064	.3201185
5354	.3300551
5656	.3400621
5966	.3500406
6286	.3600736
6614	.3700779
6958	.3802857
7294	.3900022
7652	.4000890
8014	.4100029

8390	.4200231
8780	.4301150
9174	.4400266
9582	.4500114
10006	.4600886
10438	.4700647
10888	.4801658
11342	.4900753
11810	.5000067
12296	.5100414
12796	.5200841
13304	.5300110
13834	.5400755
14374	.5500373
14950	.5603469
15520	.5702448
16100	.5800138
16726	.5902292
17358	.6002103
18000	.6100324
18686	.6201795
19378	.6300753
20110	.6401809
20868	.6502733
21628	.6600234
22448	.6701505
23292	.6801677
24156	.6900146
25074	.7000494
26026	.7100192
27026	.7200412
28072	.7300553
29162	.7400037
30324	.7500928
31530	.7600065
32822	.7700000
34202	.7800234
35668	.7900059
37238	.8000251
38910	.8100017
40708	.8200021
42652	.8300512
44742	.8400629
47004	.8500632
49450	.8600018
52152	.8700396
55114	.8800061
58446	.8900563
62178	.9000450
66428	.9100062
71336	.9199995
77052	.9300063
83962	.9400136
92474	.9500031
92474	.9500031
92474	.4505109
95114	.4600049
98324	.4700410
101832	.4800060
105724	.4900051

109966	.5000014
114526	.5100035
119418	.5200156
124662	.5300094
130298	.5400061
136306	.5500053
142700	.5600014
149518	.5700014
156794	.5800005
164398	.5900041
172260	.6000000
180402	.6100013
188844	.6200098
197572	.6300008
206620	.6400021
215998	.6500095
225716	.6600131
235780	.6700018
246242	.6800078
257096	.6900054
268358	.7000004
280076	.7100111
292238	.7200000
304928	.7300071
318152	.7400033
331992	.7500131
346454	.7600082
361612	.7700015
377564	.7800102
394338	.7900016
412072	.8000062
430838	.8100054
450776	.8200065
472018	.8300003
494750	.8400000
519146	.8500001
545468	.8600038
574018	.8700036
605182	.8800038
639428	.8900002
677442	.9000002
677442	.9000002

ANNEX E
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EXAMPLE OUTPUT OF OPTIMAL STOCKPILES

Below is a listing of the optimal stockpiles for On-Hand Stocks (Small Article 5) and Readiness Requirements (Large Article 5).

On-Hand Stockpile	
Mun 1	1
Mun 2	1
Mun 3	1000
Mun 4	1
Mun 5	16
Mun 6	1000
Mun 7	61
Mun 8	258
Mun 9	1
Mun 10	1
Mun 11	638
Mun 12	1
Mun 13	797
Mun 14	1
Mun 15	690
Mun 16	201
Mun 17	1
Mun 18	1
Mun 19	1
Mun 20	422
Mun 21	1000
Mun 22	1
Mun 23	1
Mun 24	1
Mun 25	1
Mun 26	1000
Mun 27	135
Mun 28	373
Mun 29	1
Mun 30	3
Mun 31	1000
Mun 32	81
Mun 33	1
Mun 34	1
Mun 35	1
Mun 36	1
Mun 37	1
Mun 38	1
Mun 39	1
Mun 40	1
Mun 41	1000
Mun 42	1
Mun 43	1
Mun 44	1
Mun 45	1
Mun 46	1000

Mun 47	1
Mun 48	1
Mun 49	1
Mun 50	1
Mun 51	1000
Mun 52	1
Mun 53	366
Mun 54	1
Mun 55	109
Mun 56	120
Mun 57	1
Mun 58	1
Mun 59	1
Mun 60	1

Fraction of Expected Target Value Destroyed .9500031

Total Cost 92474

Readiness Requirements

Mun 1	5353
Mun 2	451
Mun 3	1000
Mun 4	1
Mun 5	16
Mun 6	1000
Mun 7	1588
Mun 8	5219
Mun 9	1
Mun 10	1
Mun 11	3613
Mun 12	1
Mun 13	10000
Mun 14	1
Mun 15	690
Mun 16	201
Mun 17	3
Mun 18	1
Mun 19	1
Mun 20	3134
Mun 21	1030
Mun 22	1
Mun 23	10000
Mun 24	1
Mun 25	9139
Mun 26	10000
Mun 27	236
Mun 28	668
Mun 29	1
Mun 30	3
Mun 31	1000
Mun 32	81
Mun 33	814
Mun 34	1
Mun 35	1
Mun 36	1
Mun 37	1
Mun 38	1
Mun 39	1
Mun 40	1
Mun 41	1000
Mun 42	1
Mun 43	10000
Mun 44	1

Mun 45	1
Mun 46	2949
Mun 47	1
Mun 48	1
Mun 49	1
Mun 50	1
Mun 51	1090
Mun 52	1
Mun 53	4904
Mun 54	1
Mun 55	109
Mun 56	120
Mun 57	1
Mun 58	1
Mun 59	1
Mun 60	1
Fraction of Expected Target Value Destroyed	.9000002
Total Cost	677442

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The NATO Defence Requirements Review (DRR) has developed 26 Planning Situations for Force Development and Stockpile Guidance. These Planning Situations range from potential Article 5 Operations, to Peace Support Operations and Other Security Interests. The Canadian Department of National Defence has been developing analytical methods for force planning using Scenarios. These methods have included balancing Cost and Risk using Marginal Analysis ("Best Bang for the Buck") algorithms. The salient feature of these models is that they result in an intuitive graphical presentation of Cost and Risk in which Risk is reduced as Cost increases. However, there is a state of diminishing returns in which inordinate Cost is incurred to remove the last percentages of Risk. Therefore, military decision-makers can develop an "optimal" Force Structure that achieves maximum cost savings at minimum risk. The Canadian Marginal Analysis approach is adapted, in the following paper, to the NATO Planning Situations to examine the Cost/Risk relationship in the Ammunition Stockpiles.

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